Tactical Utility of Tailored Systems

2015 Mad Scientist Symposium.

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"Not only could this change the way the government uses your tax dollars — think about it, instead of having a 10-year lead time to develop a piece of equipment, if we were able to collapse the pace of which that manufacturing takes place, that would save taxpayers billions of dollars — but it also could get technology out to the theater faster, which could save lives"

—President Barack Obama

"I think the American tendency—and I'm sure this is often the case in business as well—is to emphasize change over continuity. We're so enamored of technological advancements that we fail to think about how to best apply those technologies to what we're trying to achieve. This can mask some very important continuities in the nature of war and their implications for our responsibilities as officers." ***—General H. R. McMaster***

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **10 JUL 2015**	2. REPORT TYPE	3. DATES COVERED **00-00-2015 to 00-00-2015**

4. TITLE AND SUBTITLE **Tactical Utility of Tailored Systems**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Robert Smith**	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **US Army RDECOM-TARDEC,6501 E. 11 Mile Road,Warren,MI,48397-5000**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
2015 Mad Scientist Symposium

14. ABSTRACT
None.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**17**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The Army is traditionally shaped to confront what is expected, but winning in a complex world requires fighting an unknown enemy. Future enemies will have access to off-the-shelf technologies that previously only large nation-states could afford. Meanwhile, large nation-states are able to duplicate or steal US high-technology investments at a fraction of the research cost. For example, Figure 1 shows Chinese replications Big Dog and the Switchblade Tube Launched Drones. Even if the technology knock-offs are substandard, they still negate the US return on investment (ROI) of the raw technology development cost. No longer can the US spend billions to develop the next stealth technology and expect a twenty-year payoff. Acquisition programs in all services already struggle to meet prescribed timelines and remain within budget. This paper hopes to explore the idea of combining virtual environments and rapid manufacturing to create tailored materiel specific to region or even battle. This powerful process innovation aims to tilt the cost/effectiveness calculation back in the favor of the United States.

Figure 1: China rapidly duplicates DARPA and other US investments often improving on designs. Sources[1,2].

In the 1970s, the US chose to offset the USSR's superior numbers using high technology. This led to the development of the Abrams Tank and Bradley fighting vehicle (along with precision munitions, and stealth technology). Nevertheless, by doctrine, vehicles must perform interchangeably anywhere in the world. The enemy is now unknown, but equipment must perform multiple functions while still ensuring maximum capabilities for our warfighters. This had led to the development of over-specified "exquisite" systems that require extraordinary (and

[1] Lin, Jeffrey, Singer P.W. (2014, September 5). "Da Gou", China's Own Big Dog Robot. *Popular Science*. Retrieved from http://www.popsci.com/blog-network/eastern-arsenal/da-gou-chinas-own-big-dog-robot

[2] Chinese Combat Recce Vehicle Displayed with Copies of US Killer Micro-Drones. *Defense Update*. Retrieved from http://defense-update.com/20141113_chinese-combat-recce-vehicle-displayed-with-copies-of-us-killer-micro-drones.html

expensive) technology leaps. A recent example is the Ground Combat Vehicle concept (GCV). The GCV requirements, to include a three-man crew, nine dismounts, high protection, and lethality levels, lead to an exquisite system. The result is a "tactically repulsive" 75-85 ton vehicle that will require exotic technology leaps to become useful (Figure 2). The Colbert Report in Figure 3 provides another tongue-in-cheek representation of an exquisite system.

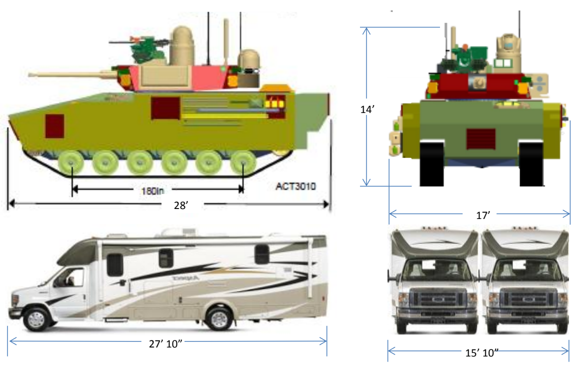

Figure 2: The GCV is a prime example of an exquisite system.

Figure 3: Humorous example of an exquisite system.

In contrast to exquisite systems, tailored systems focus on specific functions, specific geographic areas, or even specific fights. The narrow focus allows high performance to be achieved without the development of exotic and expensive technologies. Again, exquisite systems must achieve high performance across multiple domains, which drive outlandish costs. The tip of the future spear (Figure 4) could be inexpensively sharpened by developing highly tailored systems that perform a limited mission set extremely well. Due to the specificity of these systems they need to be either manufactured on demand or modular. Neither true modularity or rapid production have ever actually been demonstrated. Both require investments in process technologies. These technologies will be hard for our enemies to duplicate since they return the advantage to the large bureaucracy required to enable such a methodology.

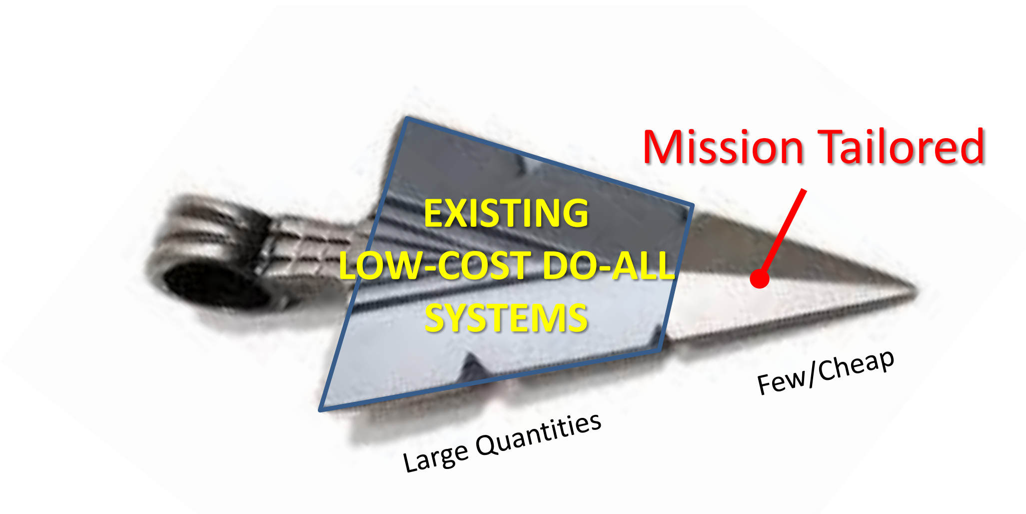

Figure 4: Mission / regionally tailored systems will outperform do-all exquisite systems at lower cost.

The logical limit of rapid manufacturing would be to create a procurement system to produce materiel at a cost low enough to make equipment disposable. Further cost savings may be realized by upgrading existing commodity Army assets such as HMMWVs (with protection levels unsuitable for manned missions) with autonomy kits. These newly autonomous systems can perform mundane and dangerous resupply missions. A further advantage of tailored systems is they will force the enemy to deal with a variety of unknown US assets perhaps seen for the first time. Since protection and lethality will be unknown to the enemy, it will be asymmetrically challenging for them to develop TTPs and materiel to counter the United States.

An excellent historic example of tailored systems is Hobart's Funnies[3], which sharpened the tip of the amphibious assault phase of the Normandy D-Day invasion during World War II. The failed Allied raid at Dieppe in August 1942 showed how difficult it was to land vehicles and men during an amphibious invasion. Specialized armor was needed to get across soft sand and through beach obstacles. Major General Sir Percy Cleghorn Stanley Hobart was responsible for the development of specialized armored fighting vehicles. These unusual vehicles were key enablers to break through German coastal defenses. Hobart developed equipment and tactics that

[3] Talarico, J. The 'Funny' Tanks Of D-Day. Retrieved from http://www.iwm.org.uk/history/the-funny-tanks-of-d-day.

not only improved on existing designs, but also created entirely new technologies. Figure 5 shows examples of several of his dozens of tailored creations.

Figure 5: A small sampling of Hobart's Funnies.

Figure 6: Textron Scorpion Light Attack Jet. Source[4].

A more recent case study is the Scorpion light attack jet as shown in Figure 6. Textron announced the Scorpion in 2013 at an Air Force Association technology conference. The Scorpion costs about $20M, built from off-the-shelf components, and went from concept to first flight in 23 months. Compare this to the exquisite F-35 Lightning, which hit the drawing board in the early 1990s and costs about $157M. Granted the Scorpion and F-35 are not an apples-to-apples comparison, it still bounds the problem. A closer comparison was offered by Bill

[4] Hotten, R. (15 July 2014) Farnborough Airshow: The Scorpion in Search of a Customer. *BBC News.* Retrieved from http://www.bbc.com/news/business-28260781.

Anderson, President, Textron AirLand, who pointed out[4] the US is currently using its F-16 super-jet on low-end missions in Afghanistan. "There's no air-to-air threat there. They are spending $18,000 an hour running the F-16. You're burning the life of the aircraft on missions it was not designed for." says Mr Anderson. In contrast, Textron is targeting a Scorpion operating cost of $3,000 an hour.

The immediate reaction of most acquisitions personnel to the idea of tailored systems will likely be to object because the maintenance and logistics of fielding a hugely varied fleet of tailored vehicles will be a nightmare. Again, with an investment in technology, maintaining highly varied vehicles is entirely possible. The key is to develop a well-tracked digital manufacturing database of replacement parts. With the advent of 3-d printing and digital manufacturing, a new part may be procured as easily as scanning a bar code and pressing print. Augmented reality goggles can be then used to show mechanics step-by-step how to repair the equipment and what tools to use. Currently mechanics rely on learning the equipment and memorizing many of the maintenance procedures. Using display technology to substitute for physical gauges, the driving interface and preferences for the Soldier could follow them to each vehicle they drive. Essentially the gauges could be similar to setting up their custom iPhone apps. This would reduce training needs. The future Soldier will need to focus on information warfare and tactics/ creativity/ strategy – not on oil pressure. Smart displays should help Soldiers understand performance envelopes at a glance with no practice or training.

Figure 7: The ARMAR augmented reality system guides a Soldier through a repair. Source[5].

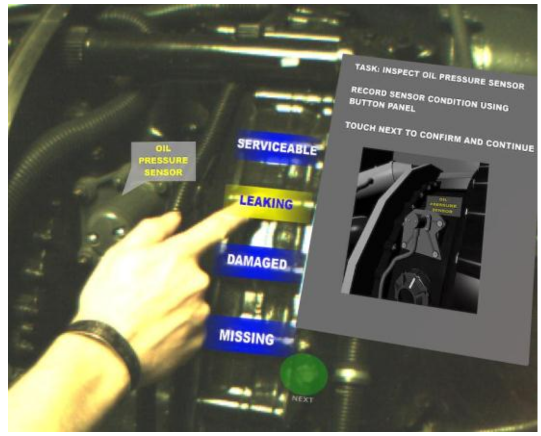

Figure 8: A close up of what the Soldier is seeing in the ARMAR display. Source[5].

The Army for over a decade has been holding up modularity as a method to achieve system tailoring. The Future Combat Systems program is an excellent example of the closest success of a modular combat vehicle. The idea of a pickup-truck common chassis with a switchable mission module is usually the first thing that most people imagine when they think of modularity. FCS failed to produce a truly common chassis because of completely different needs between the "shooter" and "carrier" versions. Any time something is modularized, it adds some sort of interface burden. A specific-built system will always out perform a modular system for this reason, but clearly, this limits its resilience as well. There is a clear advantage to modularity at the component level for reducing logistics burden and engineering costs associated with unique components. Embracing the modularity of components is highly useful, but it is not a panacea. There are many ways to make systems modular that acquisitions professionals should consider as illustrated in Figure 9 . As rapid manufacturing matures, a tension will develop between custom production and modularity. DOD investments should be made to capitalize on this opportunity.

[5] Henderson, S., Feiner S. Augmented Reality for Maintenance and Repair (ARMAR). *Columbia UniversityComputer Graphics & User Interfaces Lab.* Retrieved from http://monet.cs.columbia.edu/projects/armar/

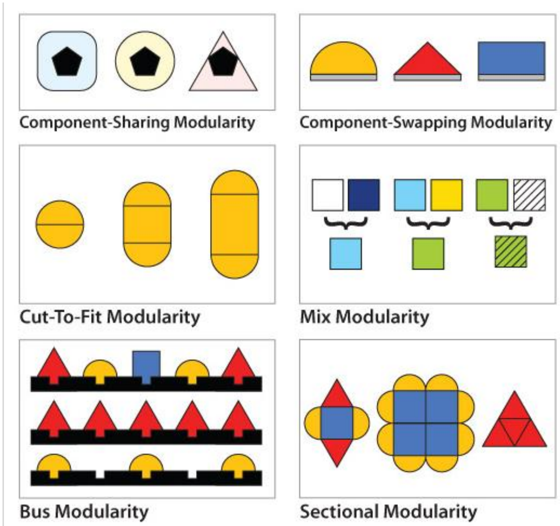

Figure 9: There are many ways to utilize modularity beyond just swapping mission modules. One example would be making a fleet of vehicles that all look the same on the outside, but the interior is completely swapped out. Source[6].

The ARCIC Early Synthetic Prototyping Concept

The ARCIC Early Synthetic Prototyping (ESP) initiative offers a viable methodology to determine which materiel is optimal for specific battles via crowdsourced gaming environments. ESP enables thousands of Soldiers to tailor tactics, strategies, force structures, and materiel to try and minimize cost and to maximize mission effectiveness. ESP hopes to harness the free flow of ideas between technologists, program offices, and Soldiers to identify and assess concepts early in the design phase at a time when costs are low. Gaming is not new to the Army. What is unique about Early Synthetic Prototyping is the idea of launching an ongoing experiment and gaining access to thousands of Soldiers' experience and brainpower. ESP players could be anyone from a Private fresh out of boot camp to a thirty-year veteran with extensive combat experience. Given the dire need of the United States to infuse innovation and to explore agile responses into acquisitions, the ESP process may lead to a new Revolution in Military Affairs (RMA). The - 9/11 Commission, The 9/11 Commission Report "Imagination is not a gift usually associated with bureaucracies. It is therefore crucial to find a way of routinizing, even

[6] Flahert, J. (April 19, 2009). 6 Types of Mass Customization. *Replicator*. Retrieved from http://replicatorinc.com/blog/2009/04/6-types-of-mass-customization/

bureaucratizing the exercise of imagination. Doing so requires more than finding an expert who can imagine that aircraft could be used as weapons."

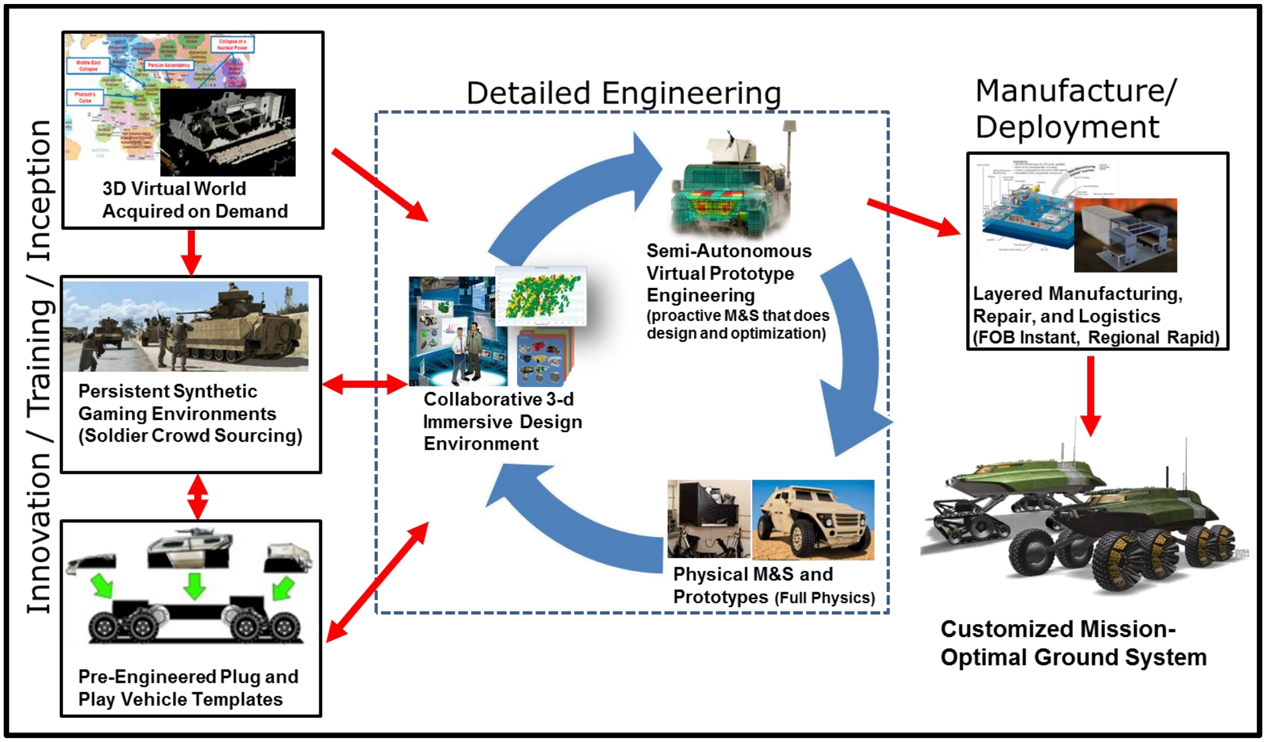

Figure 10. Ground Systems SE/2025 "Systems Engineering" Process. Source[7].

Figure 10 shows a notional Systems Engineering 2025 process[7] that uses ESP virtual wargaming with rapid manufacturing to tailor systems and force structures. The entry point into the process starts with Early Synthetic Prototyping (left center) which allows thousands of Soldiers to "kick the tires" of capabilities. Soldiers will pool their collective expertise to co-design vehicles with engineers while simultaneously optimizing the best doctrine including force structure. Soldiers will be able to modify vehicles in this synthetic world before any metal is bent and see how their modifications stack up against realistic mission objectives. Potentially, even real-time scenarios will be rehearsed by using UAVs and satellites to instantaneously create geo-specific environments as shown in the upper left of Figure 10. In order to avoid overwhelming the users with choices from the infinite combination of vehicle technologies, vehicle templates, and

[7] Smith, R. E., & Vogt, B. D. (2014). A Proposed 2025 Ground Systems, Systems Engineering Process. *Defense Acquisition Univ*. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA608885

capability modules will be evolved within the gaming environments as shown at the lower left of Figure 10. Vehicle templates are preferred configurations of modules and technology that the "crowd" of Soldier-gamers proves to be robust for mission effectiveness. The templates will adapt over time as users share amongst themselves and piggyback on the best ideas.

Finding the sweet spot among competing objectives (performance, unit cost, O&S costs, development risk, and growth potential) is a non-trivial task. Ultimate metric is affordable mission success. Materiel and tactical employment are not separable in real world. Early Synthetic Prototyping looks to change the requirements development process from a linear document centered process based on subject matter input to a data based approach. Thousands of scenarios measured using objective metrics (such as mission success rate). Due to the volume of input, the robustness of solutions may be evaluated. Expert opinions will still be interjected into the process as SMEs will have to make sure technologies and costs are correctly represented. Experts on tactics and strategy (such as MCoE) will still need to review the outcomes.

Tactical Utility = Mission Success / Total Cost

The gaming environment will help inform SE tradespace exploration by producing a new "tactical utility" metric which will measure statistical battlefield effectiveness of various engineering solutions over multiple vignettes. Allowing Soldiers to test-drive virtual systems in various operations will allow program managers to compare system versatility and tactical utility against cost, schedule, and risk. Future program managers will likely have a new option to produce nearly disposable, specific purpose vehicles if that approach provides a life-cycle cost savings to the government.

Pre-Engineered Plug and Play Vehicle Templates

A template in the context of future vehicle design is an assembly of modules and custom production items that is a doctrinal preference for a successful outcome. Templates are key to the rapid fielding of different solutions based on terrain, enemy, mission, or other considerations. Imagine a case where there will be a sustained operation requiring the capture of insurgents. Users should be able to select pre-engineered vehicle templates to try out in advance to see what works best. Once they find that a robot or tank works well, they can tailor the template vehicle to their tastes and preferences. Having a generic starting template is important in case an event occurs that requires an immediate response that allows no time to customize vehicles beyond what is captured already in the template. This is also important for experimenting in the gaming environment so players have base vehicles to play with in the virtual environment without starting from scratch. The development of templates encourages innovative evolution of designs within the gaming environment by allowing easy modifications. Again, there is a combat advantage to tailoring because it will confound the enemy's ability to exploit a common vulnerability because the *Achilles' heel* might always change.

Templates, along with modularity, are critical to avoid decision paralysis in the face of too many options. Information overload directly reduces the human ability to make smart, creative, and successful decisions. As promising vehicle configurations evolve from the persistent gaming environment, these can be tied to classes of use-cases and archetypes or templates may be defined. These templates represent the doctrinal basis for a vehicle that may be deployed and progressively tailored as more information about a conflict or the greater the probability of a certain type of event occurs as shown in Figure 11. Individual commanders will be able to customize the base templates as needed for specific missions– be it in the real world or virtual world. This evolving design methodology is supported by having discussion forums and replay capabilities for Soldiers to discuss what options are most desirable and to share first-person virtual operational experiences with other stakeholders.

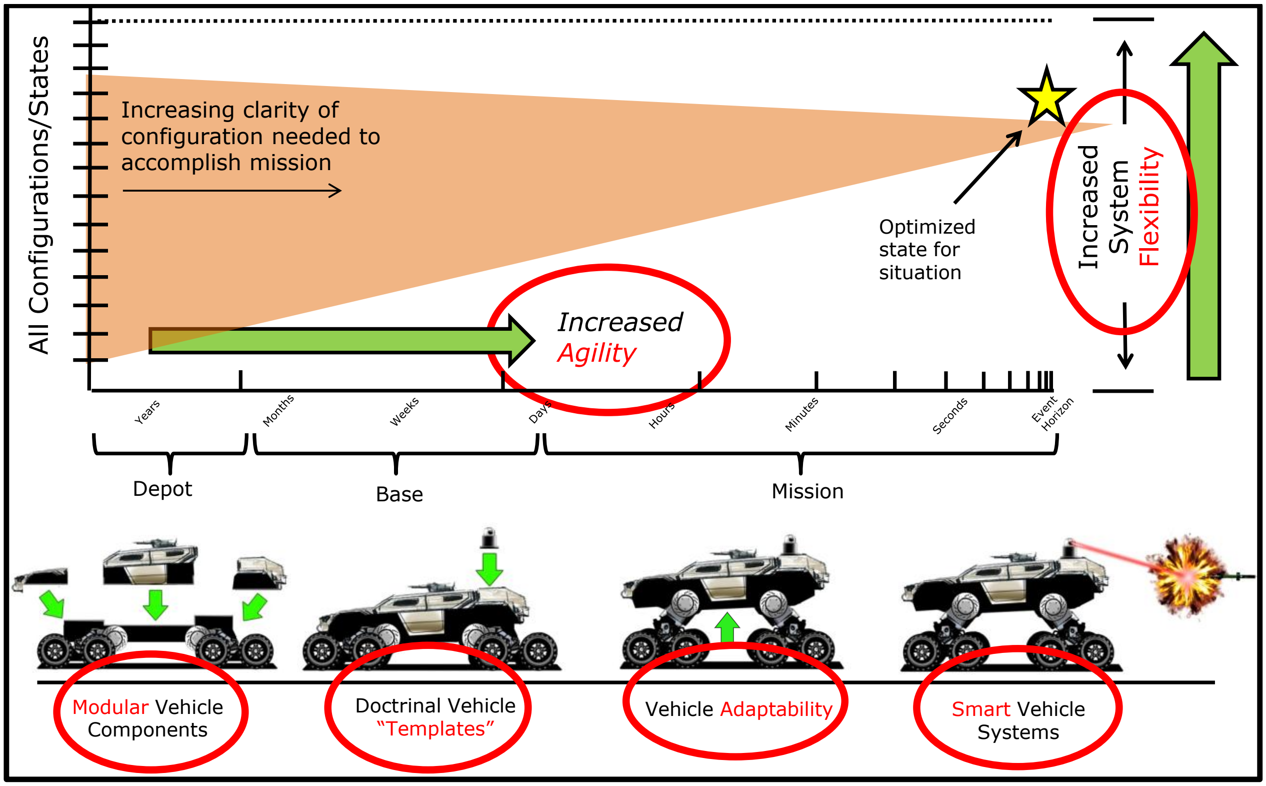

Figure 11. Templates of modular vehicles and a plan for manufacturing, and logistics will become inseparably coupled in the future. Source: Michael T. Rose (TARDEC).

Layered Manufacturing, Repair, and Logistics

The future force might be substantially redefined by new options presented via rapid manufacturing and particularly additive manufacturing. Per Wikipedia[8], "Rapid manufacturing is a technique for manufacturing solid objects by the sequential delivery of energy and/or material to specified points in space to produce that part." 3-d printing reduces the number of separate machines necessary to create a part by transforming powdered or liquid raw materials layer-by-layer into a final piece. Additionally, additive manufacturing allows the elimination of welding, brackets, and flanges when the piece can be produced as a whole. Conventional machining processes remove material which creates waste, where additive manufacturing only places material where needed. Finally, additive manufacturing may also be used to make repairs.

[8] Rapid manufacturing. (n.d.). Retrieved from http://en.wikipedia.org/wiki/Rapid_manufacturing

General Electric has demonstrated an ability to repair worn parts by using a precision spray technique to add material to an existing part[9].

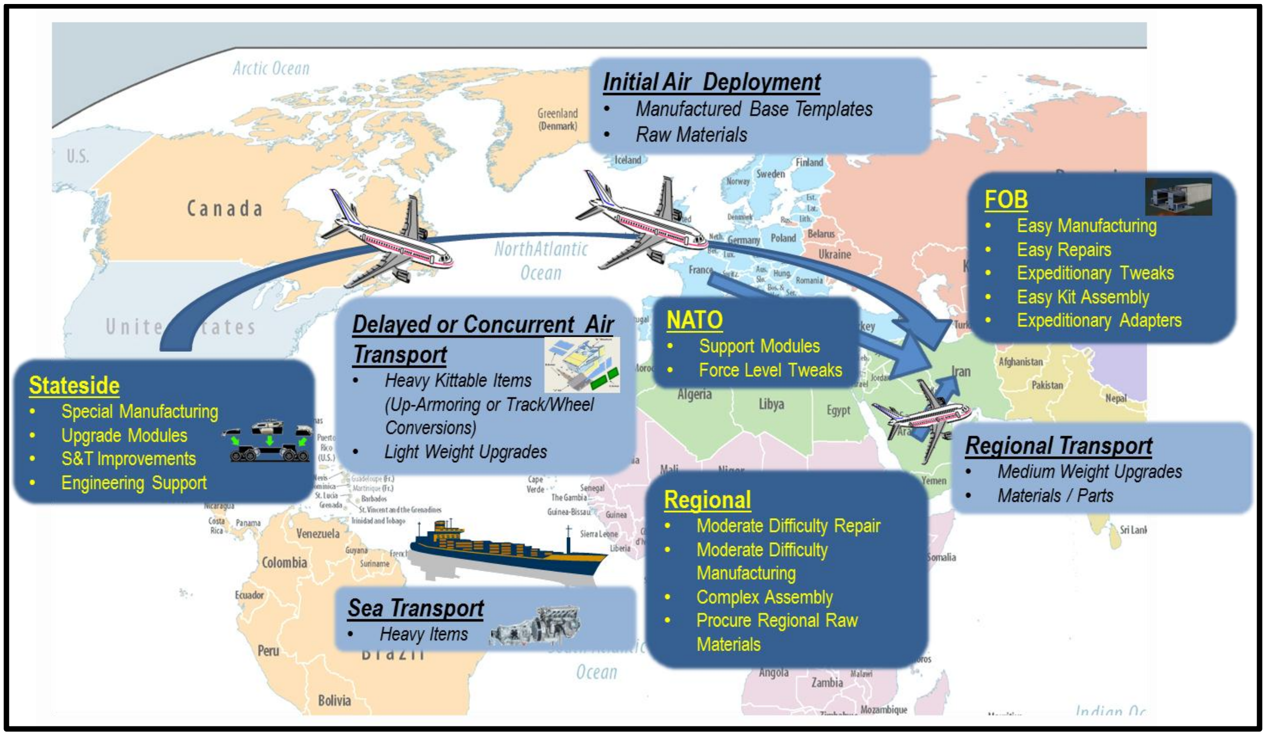

Figure 12. Notional Future Layered Manufacturing/ Repair/ and Logistics. The movement of materials and manufacturing equipment will be optimized to provide maximum flexibility and minimal cost.

A new ability to produce parts locally may substantially change procurement and repair logistics. Future logistics (notionally illustrated in Figure 12) must optimize the movement of materials and manufacturing equipment to provide maximum flexibility and minimal cost. Items that require large amounts of energy, materials, and specialized environments will likely be produced stateside. Some items may be manufactured at the forward operating base (FOB) using technologies such as 3-d printing. The Navy explored the notion of ships becoming floating factories in a *Proceedings* Article[10], possibly even harvesting resources from the surrounding

[9] (2013, November 8). GE researchers experiment with 3D painting to build up and repair parts. Retrieved from http://phys.org/news/2013-11-ge-3d-video.html

[10] Cheney-Peters, S., & Hipple, M. (2013, April). Print me a cruiser! *Proceedings Magazine, 139*. Retrieved from http://www.usni.org/magazines/proceedings/2013-04/print-me-cruiser

seas or ashore. Due to the intrinsic complexity of customized platforms, it will be critical to use information technology to form an effective manufacturing and logistics strategy.

CPT Elsmo[11] provides a simplistic storyline example: "A tank, or any other form of modular equipment that is not part of the first wave of combat force, would not necessarily be standard equipment for a deploying unit. In the Army After Next, modular equipment could be created specifically for the contingency and be assembled during transit. The chassis may come from one location, while the turret may be sent from another, with the two marrying up in the theater of operations. The new piece of armor then would be employed during the logistics pulse or refit phase of the operation." In reality, a ground system will probably have multiple components coming from a variety of locations. Assemblies and sub-assemblies may be created anywhere in the logistics and manufacturing chain. This gives a very new meaning to what the life cycle of a product and its constituent modules may become.

It may even be possible to use manufacturing robots on ships or at a Forward Operating Base to completely tear down, upgrade or repair vehicles. One Navistar Maxxpro reset program shipped trucks all the way back to Mississippi to outfit them with a new automotive chassis using inexpensive local labor. It would have been much less expensive to ship the new chassis to theatre and use robotics to autonomously rebuild the trucks. Figure 13 notionally shows how this might look.

[11] Elsmo, E. S. (1999, May-June). Modular design for future logistics. *Army Logistician, 31*(3). Retrieved from http://www.almc.army.mil/alog/issues/MayJun99/MS327.htm

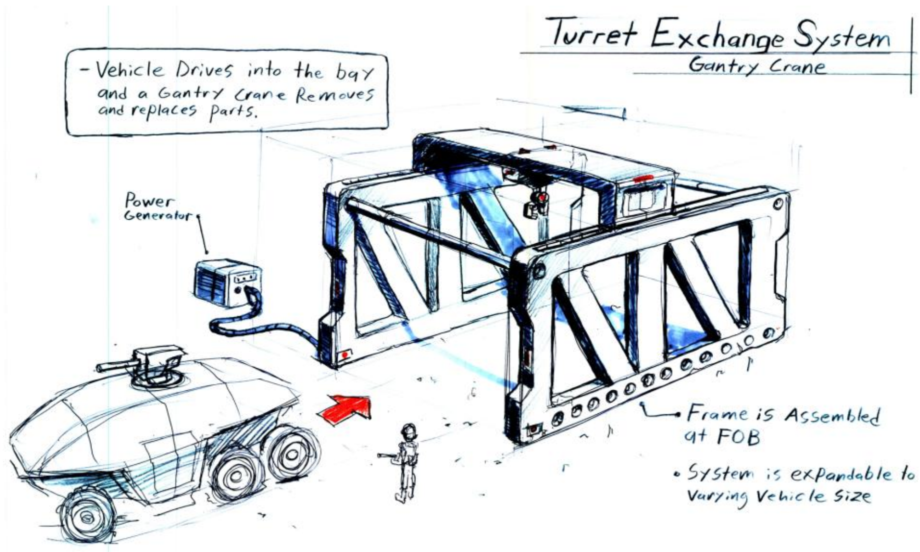

Figure 13: Artistic rendition of an in-field robotic system to swap out parts of perform repairs.

The notion of local manufacturing is not entirely new to the Army. TARDEC had fielded a mobile parts hospital in the past, which was the automotive equivalent to the mobile army surgical hospital (MASH) unit, providing treatment to a vehicle so its crew is protected and could finish the mission[12]. The Rapid Equipping Force began fielding expeditionary lab mobile (ELM) units in 2013, which include 3-d printers, computer-assisted milling machines, and laser, plasma, and water cutters, along with common tools like saws and welding gear[13]. The industry is fast approaching a point where even static structures such as buildings[14] may be 3-d printed. Logistics must also modernize to take advantage of these new production technologies. Boeing

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[12] Williams, M. (2004, March-April). Moving technology forward — Mobile parts hospital. *ARMY AL&T*, pp. 50-53. Retrieved from http://www.cleggind.com/50_Moving_Technology_Forward.doc.pdf

[13] Hill, D. J. (2013, February 13). 3D printing on the frontlines — Army deploying $2.8M mobile fabrication labs. Retrieved from http://singularityhub.com/2013/02/28/3d-printing-on-the-frontlines-army-deploying-2-8m-mobile-fabrication-labs/

[14] Contour crafting: Robotic construction system. (n.d.). Retrieved from http://contourcrafting.org/

has already used 3-d printing to make more than 22,000 parts used on civilian and military aircraft flying today[15].

Technology Readiness for 3-d Printing Vehicles

The development of the first crowdsourced military vehicle, the Fypmode, by DARPA and Local Motors gives a glimpse of the potential for SE/2025. Jay Rogers, founder of Local Motors, points out[16] conflicts are won not by spending tons of time and billions of dollars, but "They win it because they figured out what was going to beat the enemy, and they built that". Rogers went on to say, "Maybe we did not do the same development that [the contractor] did, to make sure the strut on the vehicle lasts a million miles. But if it saves a life, and it lasts for a whole conflict, haven't we done a better thing?" President Barack Obama was shown the Flypmode vehicle, which only took four months to produce, and enthusiastically pointed out[16] "Not only could this change the way the government uses your tax dollars — think about it, instead of having a 10-year lead time to develop a piece of equipment, if we were able to collapse the pace of which that manufacturing takes place, that would save taxpayers billions of dollars — but it also could get technology out to the theater faster, which could save lives".

The newest developments in 3-d printed vehicles debuted at the 2015 International Auto Show. Oak Ridge National Laboratories and Local Motors collaborated to print a Cobra Replica the Strati respectively. Jay Rogers claims the carbon fiber reinforced material has ballistic properties. The next logical step would be for DARPA to invest in a project to see if a 3-d printed ground vehicles, including armor could be produced to withstand ballistic and underbody threats. It may be possible to embed armor tiles and plates into the body, build compartments to fill with expedient material such as sand, or other innovations.

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[15] The future of military logistics is 3d printing. (2012, December). Retrieved from http://www.3dprintingera.com/the-future-of-military-logistics-is-3d-printing/

[16] Boyle, R. (2011, June). How the first crowdsourced military vehicle can remake the future of defense manufacturing. *Popular Science*. Retrieved from http://www.popsci.com/cars/article/2011-06/how-first-crowdsourced-military-car-can-remake-future-defense-manufacturing

Figure 14: The ORNL cobra took weeks to print, but achieves an automotive surface finish. President Barack Obama and Vice President Joe Biden view a 3D-printed carbon fiber Shelby Cobra car during a tour of Techmer PM in Clinton, Tenn. Image By: Official White House Photo by Pete Souza.

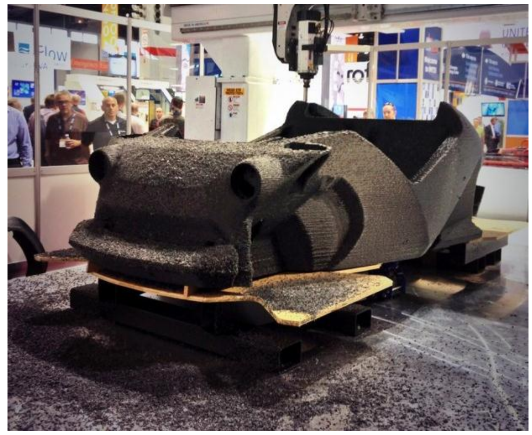

Figure 15: Local Motors Strati takes much less time to produce and has a rough finish. Source[17] .

Conclusion

The complex nature of future global conditions requires ground vehicles that are adaptable, flexible, smart, and rapidly deployable. The very nature of this type of vehicle requires an agile systems engineering process that anticipates many scenarios in advance. Using persistent synthetic gaming environments may help develop vehicle templates that consider concurrently tactics and technology. Templates will provide the most robust mission (and cost) effectiveness while still allowing for tailoring. Rapid manufacturing and non-static mission requirements are quickly making *one-size-fits-all* military ground vehicles an obsolete concept. Logistics may be transformed into a deeply interlinked manufacturing/ repair/ and logistics process with localized production and assembly of many parts or modules. The reader should consider whether the next great technology breakthrough for the Army might be an agile systems engineering process that is infused with crowdsourced Soldier input, concise communication of information, and proactive M&S tools.

[17] Krassenstein, B. (2015, Jan 10). ORNL 3D Prints Working Shelby Cobra Replica — President Obama Approves. *Popular Science*. Retrieved from http://3dprint.com/36433/3d-printed-shelby-cobra/